UNIVERSITY OF NEBRASKA COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION

Research Bulletin 171

Inheritance of Sterility, Flower Color, Spinelessness, Attached Pappus and Rust Resistance in Safflower, *Carthamus tinctorius*

CARL E. CLAASSEN
Department of Chemurgy

LINCOLN, NEBRASKA
JULY, 1952

COMMONWEALTH MYCOLOGICAL INSTITUTE
16 SEP 1954

UNIVERSITY OF NEBRASKA COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION

Research Bulletin 171

Inheritance of Sterility, Flower Color, Spinelessness, Attached Pappus and Rust Resistance in Safflower, *Carthamus tinctorius*

CARL E. CLAASSEN
Department of Chemurgy

LINCOLN, NEBRASKA
JULY, 1952

CONTENTS

STERILITY 3

FLOWER COLOR 7

SPINELESSNESS 13

ATTACHED PAPPUS 20

RUST RESISTANCE 24

SUMMARY 27

LITERATURE CITED 28

Inheritance of Sterility, Flower Color, Spinelessness, Attached Pappus and Rust Resistance in Safflower, *Carthamus tinctorius*[1]

CARL E. CLAASSEN [2]

EARLY TESTS of safflower in Nebraska (*4*)[3] and other states (*7*) demonstrated that certain varieties were adapted but were not acceptable for commercial production, primarily because of low oil content. The variability observed in this crop suggested that improvement in yield and composition should be possible through hybridization and selection. In recent years three high yielding varieties, N-6, N-8 and N-852, that average at least 32 per cent oil have been released for commercial production (*3*).

Since literature pertaining to breeding and inheritance in safflower was found to be very limited, fundamental research was instituted to determine: (A) a method for making controlled crosses, (B) the amount of natural crossing that occurs, (C) the association of oil content of seed with other seed and plant characteristics, and (D) the mode of inheritance of sterility, flower color, spinelessness, attached pappus and rust resistance. Results on natural and controlled crossing in safflower and the association of oil content in seed with other plant and seed characteristics have been reported (*1* and *2*). It is the purpose of this bulletin to report the results on the mode of inheritance for the characters studied. The data were obtained at the Scotts Bluff Field Station, Mitchell, Nebraska, and at the Box Butte Experiment Farm, Alliance, Nebraska, during the period 1943 to 1949, inclusive.

STERILITY

Two types of sterility have been observed in safflower in Nebraska (Figure 1). One type, which produces a single terminal head that is devoid of florets, has been described by Despande (*6*). Sterile plants of a different type produce a normal number of flowering heads and florets. These sterile plants usually fail to set seed, or set only a few seeds per plant (1 to 20). A fertile plant normally produces 200 to 2,000 seeds depending upon rate of planting and soil moisture.

---

[1] The data on the inheritance of sterility and a portion of the data on the inheritance of flower color and spinelessness were part of a thesis which was submitted to the Graduate Faculty of the University of Nebraska in partial fulfillment of the requirements for the degree of doctor of philosophy.

[2] At the time this manuscript was prepared, Carl E. Claassen was Associate Agronomist, Department of Chemurgy, Nebraska Agricultural Experiment Station.

[3] Refers to Literature Cited, page 28.

FIGURE 1.—Normal fertile safflower plant (left), sterile type studied in this investigation (right), and sterile type described by Despande (center).

At the time of flowering it is difficult to identify the second type of sterility studied in this investigation. Flowering occurs, but the florets on sterile plants usually do not lie on the imbricated bracts as they do on fertile plants after fertilization. After maturity sterility in most lines can usually be recognized by the completely closed imbricated bracts (Figure 2). In some varieties such as N-8 the bracts of fertile plants also remain closed. In varieties of this type it is usually necessary to press or open the heads to determine whether the plant is sterile or fertile.

Materials and Methods

Natural crosses were obtained from seed that set in sterile plants. At least 50 per cent of the seed produced on sterile plants was found to be the result of natural crosses with fertile plants. The inheritance of sterility was studied in the F_2 generation of five natural crosses. In addition, two of these crosses were studied in F_3 and one in F_4. Plants were classified after maturity as fertile or sterile on the basis of seed-set. Fertility, as considered in this investigation, refers to normal seed-set and has no reference to degree of self-fertility.

Pollen from fertile plants was applied to one head each of 10 sterile plants to determine whether seed-set would be increased thereby.

Experimental Results

Fertility was found to be completely dominant to sterility. The F_2 data from the five natural crosses are in good agreement with expectancy in a 3:1 ratio (Table 1). The number of homozygous fertile

FIGURE 2.—Mature safflower heads from a fertile plant (left) and from a sterile plant (right), about natural size.

TABLE 1.—Segregation for sterility obtained in the F_2 generation of five natural crosses.

Cross No.	Observed number plants		Chi-square [1]	P value
	Fertile	Sterile		
1	44	14	0.02	> .8
1-6-1	99	33	0.00	1.00
1-6-2	80	35	1.81	> .1
55-15	25	7	0.17	> .5
63	61	16	0.73	> .3
Sum of chi-squares (d. f. 5)			2.73	> .7
Pooled data	309	105	.03	> .8
Heterogeneity chi-square (d. f. 4)			2.70	> .5

[1] Calculated 3:1 ratio.

and segregating F_3 progenies obtained from fertile F_2 plants in two natural crosses is in good agreement with that expected in a 1:2 ratio (Table 2). The number of homozygous fertile and segregating F_4 progenies obtained from fertile F_3 plants from eight segregating lines of one cross is also in good agreement with that expected in a 1:2 ratio considering the small number of F_3 plants selected in each segregating line (Table 3).

The ten heads on sterile plants, which were pollinated with pollen from fertile ones, failed to set seed. The cytological cause of sterility was not investigated.

Data obtained on the type of sterility which produces a single terminal head that is devoid of florets confirmed Despande's (*6*) results which indicated a single factor difference. Fertility was also found to be completely dominant to this type of sterility. Since both types of sterility are inherited as single recessive factors, it should not be difficult to eliminate either type of sterility from otherwise valuable breeding material.

TABLE 2.—Segregation for sterility obtained in the F_3 progenies of fertile F_2 plants from two natural crosses.

Cross No.	Observed number of F_3 progenies		Chi-square [1]	P value
	Homozygous fertile	Segregating (3:1)		
1	18	26	1.14	> .2
55-15	9	16	0.08	> .7
Sum of chi-squares (degrees of freedom 2)			1.22	> .5
Pooled data	27	42	1.04	> .3
Heterogeneity chi-square (degrees of freedom 1)			0.18	> .5

[1] Calculated 1:2 ratio.

TABLE 3.—Segregation for sterility obtained in the F_4 progenies of fertile F_3 plants selected from eight segregating lines of one cross.

F_3 progeny No.	Observed number of F_4 progenies		Chi-square [1]	P value
	Homozygous fertile	Segregating (3:1)		
1- 4	5	22	2.67	> .1
1- 8	11	14	1.28	> .2
1-14	9	12	0.86	> .3
1-19	10	10	2.50	> .1
1-30	9	10	1.68	> .1
1-32	2	14	3.13	> .05
1-39	9	10	1.68	> .1
1-40	7	20	0.67	> .3
Sum of chi-squares (degrees of freedom 8)			14.47	> .05
Pooled data	62	112	0.41	> .5
Heterogeneity chi-square (degrees of freedom 7)			14.06	> .05

[1] Calculated 1:2 ratio.

FLOWER COLOR

The five flower colors involved in these inheritance investigations may be described as follows:

(1) White. Corolla lobes are white in the bud and for several days after flowering, turning to greyish-white upon drying.

(2) Light yellow. Corolla lobes are pale yellow in the bud and for several days after flowering, turning to greyish-white upon drying.

(3) Yellow. Corolla lobes are deep yellow in the bud and for several days after flowering, turning to a brownish-yellow upon drying.

(4) Orange. Corolla lobes are deep yellow in the bud and for 12 to 24 hours after flowering. The florets develop a reddish tint within 1 to 3 days after flowering and when dry appear orange in color. It is not possible to distinguish orange from yellow in the bud or immediately after flowering, but the two colors are easily distinguished within three days after flowering begins.

(5) Red. Corolla lobes are deep red in the bud and reddish-orange immediately after flowering, turning to deep red upon drying.

Materials and Methods

The following lines were used as parental material in the study of flower color inheritance:

Flower color	*Line number and source*	*Suggested genotype*
White	N-33, selection from Indian	ooyyCCRR
Light yellow	N-79, selection from Indian	ooYYccRR
Yellow	N-99, selection from Indian	OOYYCCRR
Orange	Indian, introduction from India	ooYYCCRR
Red	N-102 to N-105, selections from Special Russian	ooYYCCrr

Lines with white, light yellow, red, orange and yellow flower color were crossed in all possible combinations and were studied in F_1, F_2, F_3 and in a few selected F_4 progenies. Genotypes derived from the F_3 or F_4 generations of these crosses were used in new crosses in order to obtain 3- and 4-factor segregations. These crosses were studied in F_1 and F_2.

All color classifications were made when approximately 50 per cent of the heads on all plants were in flower. At this time questionable plants which occur in classifying orange and red could be checked for flower color in the bud.

Experimental Results

The F_1 and F_2 data from all possible crosses between the five flower colors are shown in Table 4. The detailed F_3 and F_4 data from these

TABLE 4.—The F_1 phenotype and suggested genotype, and F_2 segregation for flower color from all possible crosses among white, light yellow, red, orange and yellow flower color.

Flower color		Suggested F_1 genotype	Number of plants in F_2					Theoretical F_2 ratio	Chi-square	P value
Parents	F_1		Yellow	Orange	Red	Light yellow	White			
White x orange	Orange	ooYyCCRR	.....	251	.....	.....	67	3:1	2.63	> .1
Lt. yellow x orange	Orange	ooYYCcRR	.....	126	.....	32	.....	3:1	1.90	> .1
White x lt. yellow	Orange	ooYyCcRR	.....	56	.....	22	24	9:3:4	0.55	> .7
Red x orange	Orange	ooYYCCRr	.....	497	150	.....	.....	3:1	1.17	> .2
White x red	Orange	ooYyCCRr	.....	719	213	.....	286	9:3:4	3.83	> .1
Lt. yellow x red	Orange	ooYYCcRr	.....	648	193	277	.....	9:3:4	1.92	> .3
Yellow x orange	Yellow	OoYCCRR	192	85	.....	.....	.....	3:1	4.78	> .02
Lt. yellow x yellow	Yellow	OoYYCcRR	195	76	.....	99	.....	9:3:4	1.92	> .3
White x yellow	Yellow	OoYyCCRR	38	15	.....	.....	18	9:3:4	0.31	> .8
Red x yellow	Yellow	OoYYCCRr	594	146	49	.....	.....	12:3:1	0.035	> .98

crosses are not shown, but in all cases the F_2 segregations shown in Table 4 were confirmed in F_3 and F_4.

Roa (*8*) studied the inheritance of yellow, orange, red and white flower color in safflower. He suggested that the basic color of the florets was yellow and was due to the Y factor. He found that this factor was required for the expression of yellow, orange or red color. A second factor which he designated as R acting in conjunction with Y produced red color. A third factor which he designated as O acting with the Y and R factors produced orange. Roa gives the following description of yellow flower color: "Yellow florets. Yellow both when fresh and dry. Both buds and florets resemble type I (orange) when fresh, but do not change color on drying." From this description it appears that Roa was referring to yellow and not light yellow as defined in this investigation.

The results obtained in this investigation are in agreement with Roa's data if it is assumed that the yellow flower color referred to by him is light yellow and not yellow. The Y factor designation used herein is synonymous with the y factor designation used by Roa. The C factor is synonymous with Roa's R factor. Designating this factor R would be from the dominant color. The R factor used in this investigation is synonymous with Roa's O factor. Designating this factor O would again be from the dominant orange.

The yellow flower color described in this study was apparently not used by Roa. The factor which expresses this color has been designated O from recessive orange. Four factors, designated O, Y, C and R, were used to account for the ratios obtained in this investigation (Table 4). The Y and C factors are basic color factors for red, orange and yellow flower color. The Y factor alone or in any combination with O and R produces light yellow. The C factor alone or in any combination with O and R produces white. The O and R factors in any combination with recessive Y and C also produce white. The Y and C factors together produce red; Y, C and R factors in combination produce orange; and O, Y and C or O, Y, C and R factors produce yellow. The O factor is epistatic to the R factor.

Crosses between orange, white and light yellow. The F_1 plants from all possible crosses between orange, white and light yellow had orange flower color (Table 4). The F_2 and F_3 data from crosses of white x orange and light yellow x orange are in good agreement with expectancy in a 3:1 ratio.

The F_2 data of the cross white x light yellow are in good agreement with a ratio of 9 orange: 3 light yellow: 4 white. All possible F_3 ratios from this cross, including the new ratio of 3 light yellow: 1 white, were recovered.

Two factors are required to account for the segregations obtained in crosses among white, light yellow and orange. The 9:3:4 ratio obtained in the cross of white x light yellow indicates that these parents have at least one dominant factor which is required for the expression of orange flower color. The dominant factor present in the white-flowered parent produces phenotypically the same color as the double recessive. It is a basic color for orange and has been designated as the C factor. Although the dominant factor present in the light yellow-flowered parent is also a basic color factor for orange, it expresses a color in the absence of the C factor. This factor has been designated as the Y factor from the recessive light yellow.

Crosses of red with orange, white and light yellow. All F_1 plants from crosses of red with orange, white and light yellow were also orange-flowered (Table 4). The data from the cross red x orange are in good agreement with a 3:1 ratio.

The data from crosses involving red with white and light yellow indicated 9:3:4 ratios. The two new segregations 3 red: 1 white and 3 red: 1 light yellow were recovered in F_3.

Three factors are required to account for the segregations obtained in the crosses discussed above. Since orange is dominant to red the new factor has been designated as the R factor. All three factors, Y, C, and R, are required for the manifestation of orange flower color. The red-flowered parent is dominant for the Y and C factors, but recessive for the R factor. Since two-factor segregations were obtained in crosses of white x red and light yellow x red, both the white and light yellow lines used as parents in these studies must be dominant for the R factor. Further evidence that the white and light yellow parents were dominant for the R factor is indicated by the 3:1 ratios obtained in crosses of these with orange. If the white and light yellow parents did not have the R factor, 9:3:4 ratios would have been obtained in crosses with orange.

An F_2 segregation of 37 red: 16 light yellow: 16 white was obtained from a cross of a white-flowered line obtained from the F_3 ratio of 3 red: 1 white (yyCCrr genotype) with a light yellow-flowered line obtained from the F_3 ratio of 3 red: 1 light yellow (YYccrr genotype). This is a good fit with the expected 9:3:4 ratio, chi-square value of 0.90, P value between .8 and .7.

Crosses of yellow with orange, light yellow and white. The F_1 plants of crosses of yellow with orange, white, light yellow and red all had yellow flower color (Table 4). Although the F_2 data from the cross yellow x orange are in only fair agreement with expectancy in a 3:1 ratio, the F_3 data from this cross are in good agreement with expectancy. The factor which expresses yellow flower color has been designated O, from the recessive orange.

The F_2 data from the cross white x yellow are in good agreement with a ratio of 9 yellow: 3 orange: 4 white. The new segregation of 3 yellow: 1 white was obtained in F_3. The F_2 data from the cross light yellow x yellow are in good agreement with a ratio of 9 yellow: 3 orange: 4 light yellow. An insufficient number of F_3 progenies was grown to recover the new segregation 3 yellow: 1 light yellow. The data from crosses of yellow with white and light yellow indicate that the C and Y factors are also basic color factors for the expression of yellow flower color.

The F_2 data of red x yellow are in good agreement with a ratio of 12 yellow: 3 orange: 1 red. F_3 progenies which segregated 3 yellow: 1 red; 3 yellow: 1 orange; and 3 orange: 1 red were obtained. The O factor is epistatic to the R factor.

Multiple factor segregations. Since the interaction of the four factors, O, Y, C and R, has been determined from all possible crosses between white, light yellow, red, orange and yellow, the expression of flower color in the 16 homozygous genotypes should be as follows:

Genotype	*Flower color*	*Nebraska accession number of genetic stocks*
OOYYCCRR	Yellow—Genotype of parent	N-99
OOYYCCrr	Yellow	N-596-4-15
ooYYCCRR	Orange—Genotype of parent	N-3, N-6 & N-7
ooYYCCrr	Red—Genotype of parent	N-102 to N-105
ooYYccRR	Light yellow—Genotype of parent	N-79
ooYYccrr	Light yellow	N-616-4-5-6
OOYYccRR	Light yellow	
OOYYccrr	Light yellow	
ooyyCCRR	White—Genotype of parent	N-33
OOyyCCrr	White	
ooyyCCrr	White	N-598-2-10-7
OOyyCCRR	White	
OOyyccRR	White	
OOyyccrr	White	
ooyyccRR	White	N-623-1-3
ooyyccrr	White	

The following six possible three-factor and one four-factor ratios should be:

Genotype	*Three-factor segregations*
ooYyCcRr	27 orange: 9 red: 12 light yellow: 16 white
OoYyCcrr	27 yellow: 9 red: 12 light yellow: 16 white
OoYyCcRR	27 yellow: 9 orange: 12 light yellow: 16 white
OoYyCCRr	36 yellow: 9 orange: 3 red: 16 white
OoYYCcRr	36 yellow: 9 orange: 3 red: 16 light yellow
OOYyCcRr	36 yellow: 12 light yellow: 16 white

Genotype	*Four-factor segregation*
OoYyCcRr	108 yellow: 27 orange: 9 red: 48 light yellow: 64 white

A white-flowered line (N-623-1-3), genotype coyyccRR, obtained from the F_3 segregation of 3 light yellow: 1 white was crossed with the red-flowered parent. The F_1 was orange-flowered and the F_2 segregated 122 orange: 32 red: 44 light yellow: 73 white which is in good agreement with the expected 27:9:12:16 ratio, chi-square value of 2.82, P value between .5 and .3.

Another white-flowered line (N-598-2-10-7), genotype ooyyCCrr, obtained from the F_3 segregation of 3 red: 1 white was crossed with the yellow-flowered parent. The F_1 was yellow-flowered as expected and the F_2 segregated 1,322 yellow: 301 orange: 82 red: 589 white, which is in fair agreement with the expected ratio of 36:9:3:16, chi-square value of 8.70, P value between .05 and .02.

A light yellow-flowered line (N-616-4-5-6), genotype ooYYccrr, obtained from the F_3 segregation of 3 red: 1 light yellow was also crossed with the yellow-flowered parent. The F_1 was again yellow flowered and the F_2 segregated 148 yellow: 44 orange: 19 red: 58 light yellow, which is again in good agreement with the expected 36:9:3:16 ratio, chi-square value of 5.59, P value between .2 and .1.

To obtain the four-factor segregation, white-flowered line N-623-1-3, genotype ooyyccRR, was crossed with yellow-flowered line N-596-4-15, genotype OOYYCCrr that was obtained from the F_4 segregation of 3 yellow: 1 red. The F_1 of this cross was yellow-flowered as expected and the F_2 segregated 453 yellow: 127 orange: 39 red: 189 light yellow: 258 white, which is in good agreement with the expected 108:27:9:48:64 ratio, chi-square of 2.84, P value between .7 and .5.

The 3- and 4-factor ratios obtained from crosses involving new genotypes confirm the 1- and 2-factor ratios obtained in the original crosses.

In addition to the flower colors studied in this investigation, two other distinct colors have been observed. A mutant from Niphah 630, an Indian introduction, has been observed which is light yellow when it first flowers and upon drying the corolla lobes turn to a very light orange. This mutant, N-857-1, was selfed and breeds true for this color. N-804, introduced from Turkey as "Yenice 1813," apparently has a distinct flower color which appears to be different from any studied in this investigation. In the bud the corolla lobes are yellow with a splash of red. Immediately after flowering the corolla lobes are light red in color, turning to a deep red upon drying. It is possible that this flower color may be a modification of the red-flowered lines described in this investigation. There are also shades of orange flower color. No attempt has been made to differentiate these.

FIGURE 3.—Heads and leaves from spineless and spiny safflower varieties.

SPINELESSNESS

Spineless and spiny safflower types (Figure 3) have been recognized for many years. The term spineless as generally applied to safflower includes plants that are completely spineless and those that are nearly spineless. The degree of spinescence in varieties is highly variable as indicated by variation in number and length of spines on leaves, especially on the outer involucral bracts. The rigid nature of the foliaceous outer involucral bracts causes spines on these leaves to be more objectionable than those on stem leaves.

The number of spines that have been observed to develop on both sides of an outer leaf bract varies from 0 to 24 and the spine length from 1 to 6 millimeters. Spines on the same leaf are variable in length. The number and length of spines on different leaf bracts of the same plant are fairly uniform in spinescent plants, but are variable in nearly spineless ones.

Materials and Methods

The degrees of spinescence of the parental varieties and progeny were compared by means of their spine indices, calculated by multiplying the number of spines on both sides of an outer involucral bract by the estimated average length in millimeters. The spine indices of

plants which have been observed vary between 0 and 120. A plant with a spine index of 0 is completely spineless. Plants with spine indices of 1 to approximately 30 also appear to be of a spineless nature and are commonly referred to as spineless or nearly spineless. Small differences between degree of spininess can be differentiated by comparing spine indices between plants with low indices. Because of error that may occur in estimating spine length, larger differences in spine indices are required to indicate significance between plants that have high indices. Although considerable error in determining spine indices is recognized, this method of classification is considered to be a marked improvement over classifying plants as either spineless or spiny as was done by Roa (*8*) in his study of the inheritance of spinelessness.

The sources of the spineless and spiny parental varieties are as follows:

SPINELESS VARIETIES

N-1	A selection from "Yenice 1813," an introduction from Turkey
N-2	A selection from "Yenice 1813"
N-804-9	A selection from "Yenice 1813"
N-4	A selection from Special Russian
N-105	A selection from Special Russian

SPINY VARIETIES

N-101	A selection from Simla, an introduction from India
N-8	A selection from Special Russian
N-9	A selection from Debira, an introduction from Anglo-Egyptian Sudan
N-852	An introduction from Anglo-Egyptian Sudan
N-451-5-7	A selection from Pusa No. 2, an introduction from India

The segregates from cross 200 (N-105 x N-101) were studied in F_1, F_2, F_3 and in some selected F_4 lines. The segregates from cross 942 (N-1 x N-8) were studied in F_1, F_2 and in few selected F_3 lines. The other crosses were studied only in F_1 and F_2. The data from these crosses are presented to indicate the range obtained in F_2 distributions from different crosses.

Experimental Results

The classification of the parental varieties and their F_1 and F_2 progeny for their spine indices is presented in Table 5. Spininess was dominant in all crosses. Considerable variation in F_2 distributions was evident in these crosses. The segregates in cross 942 were either completely spineless or spiny and could readily have been classified on that basis. In crosses Nos. 2257, 2263, 2311 and 2281 there appeared to be a sharp division between the nearly spineless and spiny segregates.

The total numbers of F_2 plants classified as spiny and nearly spineless in crosses where these groups could be clearly differentiated are shown in Table 6. All crosses with the exception of No. 2281 are in good agreement with expectancy in a 3:1 ratio.

N-8 was used in three different crosses (Nos. 942, 2257 and 2263). The three F_2 distributions show considerable variation, especially in the nearly spineless segregates. Both N-2 and N-4 have an average spine index of 5. However, the nearly spineless segregates of the cross which involves N-4 are nearer complete spinelessness than those from the cross which involves N-2.

N-9, a very spiny variety, was also used in crosses involving N-2 and N-4 (Nos. 2281 and 2311). The F_2 distributions again show considerable variation. Some of the plants classified as nearly spineless are as spiny as N-852 which is considered a spiny variety. The F_2 segregation obtained in cross 2311 is in good agreement with a 3:1 or 12:4 ratio and that from cross 2281 indicates a very poor fit with a 3:1 ratio but a good fit with a theoretical 9:7 ratio. F_3 data would be required to determine the inheritance of spinelessness in these crosses.

Some completely spineless segregates have been obtained from a cross of N-2 x N-4. It is thus evident that these two nearly spineless varieties (average spine indices of 5) are not the same genetically as regards spinelessness.

F_3 progenies were grown from nine completely spineless F_2 plants from cross 942. These lines all bred true for spinelessness. F_3 progenies were also grown from 14 spiny F_2 plants from this cross. Of these, 10 segregated 3 spiny: 1 spineless and 4 bred true for spininess. This is in good agreement with the 2:1 ratio expected, chi-square value of 0.14, P value between .7 and .8.

In crosses 200, 893 and 2303 there was no clear-cut division between the spiny and nearly spineless groups (Table 5). In cross 200, F_3 progenies from 55 F_2 plants selected at random were of three general types: nearly spineless, spiny, and segregating. F_2 plants were classified as nearly spineless when all the F_3 progeny had spine indices below 28, as spiny when all the F_3 progeny were above 20, and as segregating when some of the F_3 plants had spine indices below 10 and above 45. On the basis of this classification there were 13 nearly spineless, 25 segregating and 17 spiny F_2 plants which is a good fit with a 1:2:1 ratio, chi-square value of 0.89, P value between .5 and .7.

An examination of the F_2 distribution of cross 200 after consideration of the F_3 data shows that there was an overlapping of spiny with the nearly spineless F_2 plants in the 22 to 28 per cent class. Of the F_2 plants occurring in this class, seven were selected for the production of F_3 progenies. Of these seven F_3 progenies, four were segregating and three produced progenies with spine indices all below 28. One F_2

TABLE 5.—The classification of parental varieties and their F_1 and F_2 progeny on the basis of their spine indices into 14 classes. Each class is increased by an arithmetical progression of one.

Variety or cross No.	Generation	Number of plants classified														Total number of plants	Average spine index
		0 to 1	1.1 to 3	3.1 to 6	6.1 to 10	11 to 15	16 to 21	(Spine index) 22 to 28	(Spine index) 29 to 36	37 to 45	46 to 55	56 to 66	67 to 78	79 to 91	92 and above		
N-105 X N-101, Cross No. 200																	
N–105	P_1		2	7	1	....	....	....	....	....	....	....	....	....	....	10	4.3±0.63
N–101	P_1	....	....	....	....	....	....	....	....	....	1	5	4	....	....	10	63.0±2.13
200	F_1	....	....	....	....	....	....	....	....	....	5	....	....	....	....	5	50.0
200	F_2	....	....	7	3	3	3	12	12	15	22	8	4	....	....	89	36.9±1.8
N-1 X N-8, Cross No. 942																	
N–1	P_1	X[1]	....	....	....	....	....	....	....	....	....	....	....	....	....	.....	0
N–8	P_1	....	....	....	....	....	....	....	....	....	....	X[1]	....	....	....	.....	65
942	F_1	....	....	....	....	....	....	....	....	....	1	....	....	....	....	1	50
942	F_2	107	....	....	....	....	....	1	17	52	193	77	8	5	....	460	38.9±1.0
N-4 X N-8, Cross No. 2257																	
N–4	P_1	....	....	X	....	....	....	....	....	....	....	....	....	....	....	.....	5
N–8	P_1	....	....	....	....	....	....	....	....	....	....	X	....	....	....	.....	65
2257	F_1	....	....	....	....	....	....	....	....	3	....	....	....	....	....	3	42
2257	F_2	4	21	2	....	....	....	....	....	15	44	1	....	....	....	87	34.6±2.3
N-2 X N-8, Cross No. 2263																	
N–2	P_1	....	....	X	....	....	....	....	....	....	....	....	....	....	....	.....	5
N–8	P_1	....	....	....	....	....	....	....	....	....	....	X	....	....	....	.....	65
2263	F_1	....	....	....	....	....	....	....	....	2	....	....	....	....	....	2	38
2263	F_2	....	8	3	7	12	5	....	....	17	5	86	....	....	....	143	45.4±1.8

TABLE 5.—*Continued*

N-2 X N-9, Cross No. 2311																	
N–2	P_1	....	....	X	....	....	....	....	....	....	....	....	....	....	.....	5	
N–9	P_1	....	....	....	....	....	....	....	....	...	....	....	....	....	X	.....	120
2311	F_1	....	....	....	....	....	....	....	....	....	....	....	....	....	8	8	110
2311	F_2	1	....	6	10	9	9	11	1	1	....	....	....	....	129	177	82.1±3.7
N-4 X N-9, Cross No. 2281																	
N–4	P_1	....	....	X	....	....	....	....	....	....	....	....	....	....	....	.....	5
N–9	P_1	....	....	....	....	....	....	....	....	....	....	....	....	....	X	.....	120
2281	F_1	....	....	....	....	....	....	....	....	....	....	....	....	1	....	1	80
2281	F_2	....	....	11	3	15	9	1	....	....	....	1	....	3	52	95	69.8±3.9
N-4 X N-852, Cross No. 2303																	
N–4	P_1	....	....	X	....	....	....	....	....	....	....	....	....	....	....	....	5
N–852	P_1	....	....	....	....	....	....	....	....	X	.	...	....	...	....	.....	45
2303	F_1	....	....	....	....	....	....	....	5	....	....	....	...	....	..	5	30
2303	F_2	....	4	15	8	5	2	20	28	17	...	...	....	...	....	99	24.1±1.4
N-451-5-7 X N-804-9, Cross No. 893																	
N–804–9	P_1	....	X	....	....	....	....	....	....	....	....	....	....	....	....	.....	3
N–451–5–7	P_1	....	....	....	....	....	....	....	X	....	....	....	....	....	....	.....	30
893	F_1	....	....	....	....	....	....	1	....	....	....	....	....	....	....	.....	24
893	F_2	18	1	13	48	20	24	4	5	....	....	....	....	....	....	133	10.5±0.6

[1] X refers to the average spine index of the parental variety.

TABLE 6.—The classification of F_2 progeny from five crosses as spiny or spineless. (Data assembled from Table 5.)

Cross No.	Total number of plants		Chi-square [2]	P value
	Spiny	Spineless [1]		
942	353	107	0.35	$> .5$
2257	60	27	1.69	$> .1$
2263	108	35	0.02	$> .8$
2311	129	48	0.42	$> .5$
2281	56	39	13.05	$< .01$
Sum of chi-squares (d. f. 4)			15.53	$< .01$
Pooled data	706	256	1.33	$> .2$
Heterogeneity chi-square (d. f. 3)			14.20	$< .01$

[1] The spineless plants include those that are referred to as nearly spineless.
[2] Calculated 3:1 ratio.

plant with a spine index of 20 produced F_3 progeny with spine indices all above 30. This plant was obviously incorrectly classified in F_2. Other F_2 plants with spine indices below 21 produced F_3 progeny with spine indices all below 28. Also F_2 plants with spine indices above 28 produced F_3 progeny which were either segregating or were pure spiny.

Some of the nearly spineless F_3 segregates from cross 200 were grown in F_4. A comparison between the spine indices of the nearly spineless F_2 and F_3 segregates with the average spine indices of their progeny is shown in Table 7. A statistically highly significant correlation of coefficient of 0.70 was obtained between the calculated spine indices of the nearly spineless segregates and the average spine index calculated for their progeny. A comparison between the average spine indices with their standard errors indicates that there are significant differences in the degree of spininess between the nearly spineless lines. Therefore, in addition to the major factor, modifying factors are also important in the inheritance of the degree of spininess in this cross and in all crosses studied with the possible exception of cross 942.

The F_4 line 200-3-8-42 had an average spine index of 0.06 ± 0.07 which is significantly less than the P_1 generation of the nearly spineless parent plant which averaged 4.3 ± 0.63. This indicates that transgressive segregation may have occurred. It is, however, possible that a line which has an average spine index below one could have been obtained by selecting within the spineless parent.

The F_2 segregations obtained in crosses 893 and 2303 (Table 5) are typical of those obtained in crosses involving nearly spineless and moderately spiny plants. No spineless progeny have been observed in crosses between spiny lines (N-852, N-6, N-8 and N-9) even though they were derived from entirely different sources.

It would then appear that spiny lines with spine indices above 45 have at least one common major factor for spininess in addition to an

TABLE 7.—A comparison between the spine indices of the nearly spineless F_2 and F_3 segregates of cross 200 (105 x 101) with the average spine indices of their progeny.

F_2 or F_3 plant No.	Spine index	
	Parent plant	Average of progeny
200–3– 8–42	0.5	0.6 ± 0.07
200–3– 8	6.0	3.6 ± 0.47
200–3– 8–35	0.5	3.9 ± 0.49
200–1–15–28	1.0	4.3 ± 1.03
200–5– 3	4.0	6.4 ± 0.86
200–3– 2	4.0	7.3 ± 0.60
200–2	8.0	8.0 ± 0.74
200–2–13	4.0	8.1 ± 0.87
200–1–34–32	8.0	8.3 ± 1.06
200–1– 8	12.0	8.4 ± 1.06
200–1–15–35	12.0	9.8 ± 1.25
200–1–17	24.0	10.5 ± 1.24
200–2–25	4.0	12.0 ± 1.27
200–3– 1	12.0	13.9 ± 0.72
200–1–24	24.0	14.9 ± 2.04
200–2–17	9.0	15.1 ± 1.46
200–2– 1	9.0	16.2 ± 0.92
200–1–13	24.0	19.3 ± 0.83
Average	9.2	9.5

undetermined number of modifying factors. Some varieties such as N-9 may have more than one major factor for spininess. Roa (*8*) working in India reported that spinelessness in safflower was inherited as a single recessive factor. In segregating populations he classified the progeny as spiny or spineless and made no mention of factors which modify the expression of spininess.

Application In Breeding

In breeding for spinelessness, it is important to know how nearly spineless a variety should be in order to eliminate all objectionable features of spininess. All spines longer than 1 mm. are objectionable, especially when located at the tips of the outer involucral bracts. Varieties with spine indices of 5 or less (N-1, N-2, N-3 and N-4) are spineless enough to allow roguing or hand weeding a field at any stage of growth without marked personal discomfort. Lines with spine indices between 10 and 25 are an improvement over lines with higher spine indices, but considerable discomfort occurs from personal contact with plants that have spine indices above 10. It is thus obvious that the genetic factors which modify the expression of the degree of spininess are very important in breeding for acceptable spineless varieties.

Since many degrees of spininess exist, some measure which indicates the degree of spinescence of individual plants and progenies would be

very useful in a breeding program. An indication of the reliability of the spine index in classifying individual plants in this investigation can be obtained from the highly significant correlation coefficient of 0.83 which was calculated between the spine indices of 55 randomly selected F_2 plants from cross 200 and the average spine indices of their inbred F_3 progenies. This correlation indicates that the spine index would be useful in rating individual plants for this character in a breeding program as well as in inheritance studies. After considerable practice in determining spine indices of safflower plants one becomes fairly accurate in reading spine indices without actually counting the number or estimating the length of the spines on a leaf.

ATTACHED PAPPUS

Safflower seed with attached pappus is common in many introductions and selections. The percentage of such seed from individual plants varies from 0 to 100 per cent. All commercial varieties grown in Nebraska have less than 2 per cent of seed with attached pappus.

When plants produce seed with both attached pappus and without pappus, the seed with attached pappus is formed in the central part of the heads. Also on the same plant the larger heads have a higher percentage of seed with attached pappus than the smaller heads.

The presence of a high percentage of seed with attached pappus lowers the test weight and prevents uniform feeding of seed through planting mechanisms. Therefore a variety that produces seed with more than 5 per cent attached pappus is undesirable for commercial production. In order to more intelligently breed for absence of attached pappus the inheritance of this character was studied.

Materials and Methods

N-500-6 is a selection from Special Russian which breeds true for 100 per cent attached pappus. This line was crossed with N-99 and N-798 which breed true for only a trace of attached pappus (less than 1 per cent). N-99 was selected from Indian safflower and N-798 is of hybrid origin. Cross 847 (N-99 x N-500-6) was studied more intensively than cross 851 (N-798 x N-500-6).

The percentage of seed with attached pappus was determined by counting the seed with attached pappus and without pappus. The number of seeds counted from each plant varied from 50 to 200 in F_1 and F_2 plants and was between 200 and 500 in F_3 plants.

Experimental Results

The classification of the F_2 and selected F_3 progenies on the basis of percentage of seed with attached pappus is presented in Table 8. The F_1 was intermediate in the amount of seed that had attached

pappus. The F_2 data from both crosses suggest a 1:2:1 ratio. However, there is no clear-cut division between the three groups. The F_3 data from selected F_2 plants of cross 847 indicate that there is considerable overlapping between classes in the 1:2:1 F_2 distribution. Parent F_2 plants that produced F_3 progenies which have distributions similar to that of the F_2 had percentages of attached pappus which varied from 21.7 to 94.2 per cent. Some F_2 plants which were apparently homozygous dominant for the major factor produced 61.1 and 61.6 per cent seed with attached pappus (847-3-34 and 847-3-50). Other F_2 plants which had 45.9 and 39.7 per cent attached pappus apparently were homozygous recessive for the major factor (847-3-4 and 847-1-18). The large amount of overlapping between the three groups (1:2:1 distribution) makes a definite classification of the F_2 difficult. Since the F_2 plants were not selected at random the F_3 families cannot be used directly as a basis for classifying the F_2 plants.

An attempt was made in cross 847 to determine the proper classification of F_2 plants with low percentages of attached papus. All F_2 plants with less than 20 per cent attached pappus produced F_3 progeny with low percentages of attached pappus. In the F_2 distribution of 847-1 the two plants of doubtful classification, 847-1-13 with 23.7 per cent attached pappus and 847-1-18 with 39.7 per cent attached pappus, were grown in F_3. On the basis of the F_3 distributions these F_2 plants were homozygous recessive for the major factor. This F_2 distribution could then be classified as 30 homozygous dominant or heterozygous: 9 homozygous recessive which is a good fit with expectancy in a 3:1 ratio.

An insufficient number of F_3 plants from 847-2 and 847-3 which occurred in the 22.5 to 37.5 per cent classes were grown in F_3 to make an accurate classification of these F_2 distributions. Most of the F_3 families that are segregating for the major factor appear to be in good agreement with expectancy in a 1:2:1 ratio. The data from cross 851 are presented because of the larger number of plants grown in F_2.

F_3 families which averaged below 22.1 per cent seed with attached pappus apparently are homozygous recessive for the major factor. However, many of these F_3 families differ significantly in the average percentage of attached pappus produced. Thus modifying factors are also present which influence the percentage of seed with attached pappus.

Separating seed from F_2 plants with attached pappus from that without attached pappus had no effect on the average percentage attached pappus produced in F_3 (Table 9). In breeding for absence of attached pappus nothing would be gained by hand picking the seed from individual plants for this character.

Even though a selection does have 5 or more per cent seed with attached pappus it may be possible to purify a subline from it with

TABLE 8.—The classification of the F_2 and selected F_3 progenies from two crosses on the basis of percentage seed with attached pappus.

F_1 or F_2 plant No.	Percentage attached pappus of parent F_1 or F_2 plant	Frequency distribution of individual plants based on percentage of seed with attached pappus																						Total number plants	Average percentage attached pappus
		0	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	(Class centers) 47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	100		
F_2 data, cross No. 847																									
847-1	57.2	....	2	3	2	....	1	....	....	1	....	2	2	6	3	....	....	3	2	4	2	3	3	39	58.9 ± 4.9
847-2	45.4	....	12	5	3	....	1	2	....	1	2	....	4	3	1	3	3	5	4	1	1	9	6	66	53.9 ± 4.6
847-3	63.8	1	24	11	3	1	4	2	2	4	4	8	10	7	9	7	2	1	6	4	9	17	9	145	52.5 ± 3.0
F_3 data, cross No. 847																									
847-2-17	0.8	6	10	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	16	0.6 ± 0.1
847-1-4	1.6	....	14	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	15	1.7 ± 0.4
847-3-35	5.5	....	14	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	15	2.7 ± 0.6
847-3-2	8.7	2	10	1	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	15	3.7 ± 0.9
847-1-26	7.2	....	11	....	3	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	14	3.8 ± 0.7
847-3-18	2.2	2	8	5	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	16	3.9 ± 0.8
847-3-24	6.1	....	8	8	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	17	5.4 ± 0.6
847-3-32	31.2	....	6	5	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	13	5.9 ± 1.0
847-3-47	12.3	....	8	6	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	16	6.4 ± 09
847-3-14	8.3	....	8	4	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	12	6.5 ± 1.0
847-2-2	14.5	1	8	3	3	....	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	17	6.7 ± 1.6
847-1-13	23.7	....	8	6	1	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	16	6.8 ± 1.1
847-3-49	3.3	....	8	6	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	15	7.2 ± 1.5
847-3-40	6.3	..	6	5	2	2	....	..	....	....	....	....	....	....	....	....	....	....	..	....	....	....	....	15	7.9 ± 5.3
847-1-18	39.7	....	6	6	2	....	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	16	7.9 ± 1.9
847-3-15	21.3	....	3	11	5	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	21	8.2 ± 0.9
847-1-7	14.4	....	9	2	1	....	....	1	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	14	8.7 ± 2.7
847-2-13	10.0	....	6	5	3	1	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	16	8.7 ± 1.8
847-2-11	23.9	....	2	9	3	2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	16	9.0 ± 1.1
847-3-13	24.2	..	4	3	7	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	15	9.1 ± 1.2
847-1-30	11.3	....	7	3	....	2	....	....	1	....	1	....	....	....	....	....	....	....	....	....	....	....	....	14	10.5 ± 3.1
847-3-9	30	..	3	4	5	1	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	15	11.5 ± 1.7
847-3-7	20.0	4	9	3	5	2	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	24	11.8 ± 1.6
847-3-26	25.0	3	2	4	4	2	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	16	12.2 ± 1.6
847-3-46	8.1	2	10	2	.	....	....	.	1	..	1	....	....	....	....	....	....	....	....	....	....	....	....	....	16	12.3 ± 2.7
847-3-10	4.2	3	6	2	2	3	....	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	18	12.9 ± 2.2
847-3-37	37.2	....	4	7	4	2	....	2	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	20	16.9 ± 1.7
847-3-4	45.9	....	1	2	4	8	5	3	3	2	1	1	....	....	....	....	....	....	....	....	....	....	....	....	30	22.1 ± 1.8

847-3-20	34.6		4	4				1	2	1		2			1				1	1			17	29.6 ± 7.1
847-3-30	56.6		4	....	1	...	1	2	3	..	1	1			..				1	1			15	30.2 ± 7.4
847-3-22	52.8	3	7	3	1	1	2	.	2	1	2	2			...	.	1	...	2	1	2	.	30	30.8 ± 6.2
847-3-23	64.7	.	3	1	...	1	3	1	...	2	2	...	.		..	...	...	...	....	2	....	..	15	31.1 ± 7.3
847-1-22	38.1		2	2	...	2	1	..	1	2	...	....	.	1	2	..		1	...	2	...		16	39.7 ± 7.5
847-1-19	79.1		3	1	1	1	2		1	3		3	2	4	2	2			2	...	2		29	45.7 ± 5.2
847-1-9	46.3		6	4	...		...		...	2	3	3	3	2	.			1	...	1	6		31	46.1 ± 6.3
847-1-14	78.8	.	3	...	...	.	...	1	...	3		..	1		4			1	1	1	..		15	46.1 ± 7.7
847-3-33	62.7	1	3	...	...		...	1	...		.	2	1	2	1				...	1	2		14	46.5 ± 9.4
847-3-41	64.6	..	3	...	..		2	.	1	.	2	1	1	1	..				1	2	2		16	49.6 ± 9.1
847-1-8	57.2	..	1	2	2	.	1	..		1	1	1	6	2	5	2		2	3		2		31	54.5 ± 4.8
847-3-26	87.7	1	2	2	1							2				2	.			1	4	2	17	55.8±10.2
847-3-29	90.9	.	1	2		1					2		2							1	6		15	60.6 ± 9.9
847-1-3	89.4			1	1					.	1	1		1	3	1	2			1	2		14	60.9 ± 7.4
847-1-12	94.2			2				.		1	.		1	2	1		1	1	1	1	3	1	15	66.6 ± 7.6
847-3-28	21.7				1		1			..				2	1	1	1	2	2	1	2		14	68.4 ± 6.8
847-3-50	61.1	..								.				1				2	4	3	6	1	17	85.6 ± 2.2
847-3-34	61.6	.															2	1	2	5	3	4	17	88.3 ± 2.0
847-1-5	100.0	.																		4	6	6	16	93.4 ± 0.9
847-1-23	100.0		.	.															1	2	2	8	13	93.9 ± 1.1
847-1-17	99.6			.	.			.		.	.									2	4	8	14	94.2 ± 1.0
847-2-12	100.0	..	.															1		...	1	8	6	16	97.3 ± 1.3
847-3-43	100.0	.	.			.				.										...	1	14	1	16	97.5 ± 0.5
847-2-21	100.0		.																	1	1	10	3	15	97.6 ± 0.9
										F₂ data, cross No. 851														
851-1	54.0		5	1		1		1		1		.	1	2	2	2						3		19	43.6 ± 8.1
										F₃ data, cross No. 851														
851-1-11	3.5	5	36	16	2	1																	60	2.3 ± 0.1
851-1-2	3.3	1	28	30	3	..																	62	2.9 ± 0.2
851-1-1	6.8	1	18	32	2	...				...				...		..							53	3.2 ± 0.2
851-1-6	59.8	.	7	3	3	2	2	1	2	9	4	5	4	4	1	3	1		1	1	1	7	61	46.7 ± 3.8
851-1-5	60.9	1	2	7	.	3		1			1	.	5		1	2		1		1	2	3	2	32	47.2 ± 6.8
851-1-4	50.0		7	3	1			4	1	1		2	4	5	1	2	2	3	5	1	3	1	49	54.9 ± 4.6
851-1-3	65.4	2	11	1	1		4	1	3	3	7	5	6	3	5		1	4		2	5	9	12	85	56.6 ± 3.7
851-1-15	68.2		5	5	4	2			1		3	4	2	2	6	1	6	4			6	6	4	61	58.5 ± 4.3
851-1-14	64.7	...	6	5	2	1	3	2	1	5	6	7	5	4	8	6	3	1	1		1	5	2	74	58.7 ± 3.2
851-1-7	97.2	.	.	...	.	.	....	.		.	.	.							1	3	9	18	2	33	97.0 ± 0.7
851-1-12	97.2	..										.			.			1		4	2	19	9	36	97.4 ± 0.6
851-1-9	96.2	..	...	..	.	.	....	.	.	...	...	.									3	4	24	32	99.4 ± 1.8

TABLE 9.—The effect of separating seed from F_2 plants with attached pappus from that without attached pappus on the breeding behavior of the F_3.

F_2 plant No.	Percentage of seed with attached pappus in parent F_2 plant	Percentage of seed with attached pappus in F_3 progeny		
		F_2 seed with attached pappus planted	F_2 seed without attached pappus planted	Difference in percentage of seed with attached pappus
847-3-15	21.3	10.7 ± 2.0	8.1 ± 1.0	2.6 ± 2.2
847-3-37	20.0	16.0 ± 4.6	17.2 ± 1.9	−1.2 ± 4.9
847-3-4	45.9	20.5 ± 2.2	23.9 ± 2.9	− 3.5 ± 3.6
847-3-22	52.8	27.6 ± 8.6	34.5 ± 8.8	− 6.9 ± 12.3
847-1-19	79.1	49.3 ± 7.2	38.9 ± 7.5	10.4 ± 10.4
847-1-9	46.3	50.4 ± 9.7	41.9 ± 9.0	8.5 ± 13.2
847-1-8	57.2	53.9 ± 6.9	55.2 ± 6.9	− 1.3 ± 9.7

a lower percentage of attached pappus by selecting toward complete absence of attached pappus. Obviously, the factors which modify the percentage of seed that has attached pappus are important in breeding for complete absence of this character.

RUST RESISTANCE

Rust, *Puccinia carthami* Corda, was first observed in experimental plots in 1947 (*5*). Since then rust has been observed in many commercial fields in Nebraska and Colorado. It has also been reported in experimental plots at Davis, California and Pullman, Washington.

Materials and Methods

During the 1948 and 1949 growing seasons rust on safflower in experimental plots at Scottsbluff and Alliance was severe. Resistant plants were observed in a number of introductions (Table 10). The resistant plants observed among severely rusted ones showed either no evidence of rust infection or a 1 or 2 reaction to rust.[4] The progenies of some resistant selections from these introductions were observed to be segregating for rust resistance. Others were observed to be pure for resistance.

Plant counts (resistant and susceptible) were made in 1948 on two lines, N-804-63-2 and N-804-64-3. Six plants from each of these lines were selected and selfed before their reaction to rust was known. Rust readings were recorded from the progenies of these plants in 1949. Plant counts were also made in 1949 on a number of segregating lines selected from Nebraska accessions 804, 976, 977, and 2130.

[4] 1 indicates high resistance, 2 indicates some resistance, 3 indicates susceptible but less so than 4, and 4 indicates very susceptible.

TABLE 10.—Source of introductions that had some rust resistant plants.

Nebraska accession No.	Source of seed	Reaction of resistant plants to rust [1]
804	Turkey "Yenice 1813"	1
976	Romania	0 or 1
977	Romania	0 or 1
803	Egypt (commercial sample)	2
2130	Turkey P. I. No. 161799	1
2555	France	0 or 1
2591	Morocco	0 or 1

[1] 0 indicates complete resistance, 1 high resistance and 2 some resistance but not as much as 1.

Crosses were made between rust resistant plants from various sources and rust susceptible varieties. Rust readings on the parent varieties and their F_1 progenies were obtained at Scottsbluff in 1949.

Experimental Results

The classification of plants for rust resistance in two selections from N-804 is shown in Table 11. The segregating lines from this introduction are in good agreement with expectancy in a 3:1 ratio. The progenies from the four susceptible plants were pure susceptible.

TABLE 11.—Classification of plants for rust resistance in two selections from Nebraska 804.

Selection No.	Number of plants		Chi-square [1]	P value
	Resistant (1 reaction)	Susceptible (3 to 4 reaction)		
	Segregations observed in 1948			
804-63-2	30	10	0.00	1.0
804-64-3	47	14	0.14	> .7
	Breeding behavior in 1949			
804-63-2-20	27	9	0.00	1.0
804-63-2-21	45	0	Pure resistant	
804-63-2-22	0	33	Pure susceptible	
804-63-2-23	21	4	1.08	> .2
804-63-2-24	0	31	Pure susceptible	
804-63-2-25	62	27	1.35	> .2
804-64-3-20	27	6	0.82	> .3
804-64-3-21	12	2	0.86	> .3
804-64-3-22	0	24	Pure susceptible	
804-64-3-23	45	12	0.47	> .3
804-64-3-24	0	29	Pure susceptible	
804-64-3-25	56	22	0.43	> .5
Sum of chi-squares (d. f. 9)			5.15	> .8
Pooled data [2]	327	106	0.06	> .8
Heterogeneity chi-square (d. f. 8)			5.09	> .7

[1] Calculated 3:1 ratio.
[2] From segregating lines.

Plant counts made on selections derived from 976, 977, 2130 and other 804 lines which were segregating for rust resistance indicated good fits with theoretical 3:1 ratios.

The rust reaction of F_1 plants from controlled crosses between a number of resistant lines and susceptible ones indicate that the genetic factor or factors which cause resistance to safflower rust cannot all be identical (Table 12). It is quite possible that the resistance found in 804 may be the same as that found in 2130 since these lines are quite similar in appearance, have a common origin and produced F_1 plants with the same rust reaction. Resistance in all crosses was found to be partially or completely dominant. N-977-16 breeds true for complete resistance to the race or races of this rust which have been prevalent in western Nebraska. This complete resistance has also been transferred to the F_1 plants in crosses which involved this line with a rust susceptible one.

TABLE 12.—The rust reaction of F_1 plants from controlled crosses involving a susceptible plant with various rust resistant lines.

Rust resistant line		Rust reaction of susceptible parents	Rust reaction of F_1 plants
Accession No.	Rust reaction		
977-16	0	3 to 4	0
977-15	1	do	2+
804-63-2-23-3	1	do	1+
804-19-3	2	do	2
2130-11	1	do	1+

SUMMARY

Sterility. The inheritance of sterility was studied in five natural crosses. Sterility as described herein was found to be inherited as a single-factor difference. Fertility was completely dominant to sterility. Foreign pollen as well as pollen from the same plant failed to effect seed set.

Flower color. Four factors, designated O, Y, C and R, were used to account for the ratios obtained in all possible crosses among lines with white, light yellow, red, orange and yellow flower color. The Y and C factors are basic color factors for red, orange, and yellow. The Y factor alone or in any combination with O and R produces light yellow. The C factor in the dominant or recessive condition in any combination with O and R produces white. The Y and C factors together produce red; Y, C and R in combination produce orange; and O, Y and C or O, Y, C and R produce yellow. The O factor is epistatic to the R factor.

The order of dominance of the five flower colors is yellow, orange, red, light yellow and white. The respective genotypes of the selections used as parents are OOYYCCRR for yellow, ooYYCCRR for orange, ooYYCCrr for red, ooYYccRR for light yellow and ooyyCCRR for white.

The following 3-factor ratios were obtained by crossing some of the new genotypes derived from the original crosses: 27 orange: 9 red: 12 light yellow: 16 white; 36 yellow: 9 orange: 3 red: 16 white; and, 36 yellow: 9 orange: 3 red: 16 light yellow. The 4-factor ratio of 108 yellow: 27 orange: 9 red: 48 light yellow: 64 white was also obtained.

Spinelessness. The inheritance of spinelessness was studied in detail in two crosses, Nos. 200 and 942. The degrees of spininess of parents and progeny were compared by means of spine indices calculated by multiplying the number of spines on both sides of an outer involucral bract by the estimated average length in millimeters. The parent lines of cross 200 had spine indices of 4.3 and 63.0. These parents were found to differ in degree of spininess by one major factor and an undetermined number of modifying factors. The parent lines in cross 942 had spine indices of 0 and 65. The spineless plants in the segregating populations from these crosses were all completely spineless as was the spineless parent. Spininess in this cross was conditioned by a single dominant factor.

F_2 distributions from a number of additional crosses were presented. Spininess was found to be dominant in all crosses, but considerable variation in F_2 distributions was noted in the crosses studied. In most crosses the factors which modify the degree of spininess are particularly important in breeding spinelessness.

Attached pappus. Two lines that produced a trace of seed with attached pappus were crossed with one that produced 100 per cent seed with attached pappus. This characteristic was found to be intermediate in dominance. The F_2 distributions indicated 1:2:1 ratios. Modifying factors were also found to have a marked influence on the percentage of seed that was produced with attached pappus.

Rust resistance. Resistance to the race or races of rust which are prevalent in Nebraska has been observed in a number of introductions. In segregates from N-804, an introduction from Turkey, resistance was found to be inherited as a single-factor difference. Resistance to rust in all lines tested was either partially or completely dominant.

Literature Cited

1. CLAASSEN, C. E. Natural and controlled crossing in safflower, *Carthamus tinctorius* L. Agronomy Journal 42: 381-384. 1950.
2. CLAASSEN, C. E., EKDAHL, W. G., and SEVERSON, G. M. The estimation of oil percentage in safflower seed and the association of oil percentage with hull and nitrogen percentages, seed size, and degree of spininess of the plant. Agronomy Journal 42: 478-482. 1950.
3. CLAASSEN, C. E. and HOFFMAN, ALBERT. Safflower production in the western part of the Northern Great Plains. Nebr. Agr. Exp. Sta. Circ. 87 (Revised). 1950.
4. CLAASSEN, C. E. and KIESSELBACH, T. A. Experiments with safflower in western Nebraska. Nebr. Agr. Exp. Sta. Bull. 376. 1945.
5. CLAASSEN, C. E., SCHUSTER, M. L. and RAY, W. W. New diseases observed in Nebraska on safflower. Plant Disease Reporter 33: 73-74. 1949.
6. DESPANDE, R. B. A sterile mutant in safflower (*Carthamus tinctorius* L.) Current Science 9: 370-371. 1940.
7. RABAK, F. Safflower. A possible new oilseed crop for the Northern Great Plains and far western states. U. S. D. A. Circ. 366 (Revised). 1935.
8. ROA, M. V. Inheritance of characters in safflower. Madras Agriculture Journal 31: 141-148. 1943.

2½M